Do the size, site and activity of tympanic membrane perforations relate to hearing loss in Aboriginal and Torres Strait Islander children? An observational study.

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Abstract

Objective: To investigate the effect of size, site and activity of tympanic membrane (TM) perforation on hearing loss (HL) in Aboriginal and Torres Strait Islander (ATSI) children. Design: Observational study Methodology: Children aged 5-18 years who identified as ATSI at 7 Anangu community schools within the APY Lands and Maralinga Lands of South Australia underwent 4 frequency pure-tone audiometry (0.5, 1, 2 and 4kHz) and video-otoscopy (VO). VO data was reviewed by surgeons for a middle ear diagnosis and VO files with TM perforations were then classified by perforation site (AS, AI, PS, PI, A, P, I) and size (<25%, 25–50%, 50–75% or 75–100%). Results: 575 VO files with matching audiological data were obtained. Active perforations (35dBHL; 28-44 IQR) demonstrated greater HL than inactive perforations (31dBHL; 29-39 IQR) $p=0.0029$. For inactive perforations there was a significant difference between <25% and all larger perforations ($p<0.0001$) whereas for active perforations the significance changed to between <25% ($p<0.0001$) and 25-50% ($p<0.05$) when compared to larger perforations. When perforation site was compared within all size/activity groups, no statistically different findings were identified. In all analyses findings did not change when individual frequencies were compared to 4-frequency pure tone average dBHL. Conclusion: In ATSI children from remote communities HL is greater in ears with larger perforations and active middle ear disease but there was no relationship between perforation site and HL.

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Conclusion: In ATSI children from remote communities HL is greater in ears with larger perforations and active middle ear disease but there was no relationship between perforation site and HL.

Key points:

- This study evaluated 575 ears of Aboriginal and Torres Strait Islander (ATSI) children from the An angu Pitjantjatjara Yankunytjatjara (APY) lands in South Australia and is the first of its kind in this population.
- The effect of size, site, and activity of tympanic membrane perforation on hearing loss (HL) was investigated using pure tone audiometry and video otoscopy measurements.
- HL was greater with middle ear disease activity and with increasing perforation size.
- The influence of perforation site on HL is conflicting in the literature. This study shows no significant difference in HL with perforation location in this population.
- The data demonstrates that children in the APY Lands continue to experience significant HL associated with TM perforations.

Introduction:

According to the World Health Organisation, tympanic membrane (TM) perforation rates are the highest for Australian Aboriginal and Torres Strait Islander (ATSI) children[1]. TM perforations in ATSI children become an ongoing problem into adulthood[2] and previous work from our group in remote ATSI communities in South Australia demonstrated perforation rates of 31-50% with up to 30% of individuals demonstrating activity at any one time[3]. TM perforations can result in hearing losses as high as 50dB[4]. Within Australia, ATSI children are particularly affected as data from the Australian Bureau of Statistics showed ATSI children experienced 3 times the rates of chronic otitis media (COM) as non-Indigenous Australian children[3], creating a devastating public health problem and secondary educational disadvantage in this particularly vulnerable population[5].

It has been generally accepted that hearing loss (HL) is greater with an increase in size of the TM perforation[6]. However, perforation site and the effect on hearing is more controversial with contradictory evidence regarding this[6-12]. Whilst early work showed worse hearing with posteroinferior based perforations[13, 14], others have found posterosuperior defects to be worse[11, 15]and more recent work demonstrated no difference between sites[4, 6, 7, 12]. Theories such as loss of the round window baffle effect resulting in phase-cancellation, as well as an increase in ossicular chain abnormalities have been proposed to explain increases in HL with posterior perforations. The association between an increase in size and severity of HL[4, 6, 10, 12, 16] is reinforced by bio-mechanical studies confirming the progressive loss of catenary lever ratio with enlarging perforations[17].

Objectives

The aim of this study was to investigate the relationship between perforation size, site and disease activity on HL in ATSI children in the A*n* angu Pitjantjatjara Yankunytjatjara (APY) Lands of South Australia. To date, no known study has investigated the levels of HL associated with perforation location and size in ATSI children. Additionally, this study aimed to provide an epidemiological snapshot of the hearing levels and severity of perforations in this high-risk and socio-economically deprived population.

Methods:

This paper has been prepared with reference to the STROBE checklist for cross-sectional studies.

Dataset

Data was collected as part of a larger study looking at the effect of swimming pool use on ear health[18]. Children from 7 A*n* angu community schools were studied. The A*n* angu communities are located within the APY Lands and Maralinga Lands. These lands span an area of approximately 200,000 km^2 in the far north-west part of South Australia and are home to a population of approximately 3500 – 4000 people[19]. Visits to the schools were facilitated by staff at the A*n* angu Education Service (AES) of the Department of Education (Government of South Australia). At the time of study, there was no ENT input into medical services on the Lands, essentially making this a surgically naïve and untreated dataset.

Data collection

Pure-tone audiometry was performed at 0.5, 1, 2 and 4kHz using Auraldomes to reduce ambient noise exposure. All audiometry was performed in a quiet location with ambient noise recorded as being within the range of 22-36dBA.

Video-otoscopy

Video-otoscopy (VO) footage was obtained with a WelchAllyn (Hillrom, Chicago, IL, USA) video-otoscope recorded onto a laptop.

Inclusion and exclusion criteria

Inclusion criteria:

(1) Identifies as ATSI.

(2) Aged between 5 and 18 years.

Exclusion criteria:

Incomplete VO footage preventing classification of middle ear disease.

Incomplete audiological dataset.

Classification

VO data was reviewed by ENT Surgeons (with a previously established >90% concordance) to obtain a middle ear diagnosis (Browning classification) for all children[20]. VO files with a visible TM perforation were then analysed by two medical students, one with a paediatric audiology background. They were trained by a senior ENT specialist on classifying perforation site and size. The students received a random sample of the same 20 VO files to classify independently. These classified files were then reviewed together with a senior ENT specialist and senior audiologist where > 90% diagnostic concordance was confirmed.

Perforations were classified as either <25%, 25-50%, 50-75% or 75-100%. The site of perforations was classified depending on the perforation size (Fig 1). Perforations deemed <25% were classified by quadrants: AS: anterosuperior, AI: anteroinferior, PS: posterosuperior, PI: posteroinferior. Perforations of size 25-50% were divided into anterior, inferior, and posterior locations. For size 50-75% they were classified into anteroinferior or posteroinferior locations. Perforations of 75-100% were classified as subtotal perforations. Where perforations didn't completely fit the exact regions, the closest option was chosen. Where there was any ambiguity, the VO images were reviewed by all four members of the team (the senior ENT specialist, senior audiologist and two medical students) to obtain a final classification.

Statistical analysis

Data was collected on an Excel spreadsheet (Microsoft, CA, USA) then transferred to GraphPad Prism (GraphPad Software, CA, USA) for statistical and graphical analysis. Classification of left and right ears were compared using Chi-squared analysis. Audiological data per classification was compared using Kruskal-Wallis test for non-parametric data with Dunn's multiple comparison test used to adjust p-values where appropriate. Percentage and dBHL were rounded to the nearest whole number. Non-parametric data is reported as median with 25-75% inter-quartile range (IQR) and $p<0.05$ was regarded as significant. Power analysis revealed a requirement for n=120 to achieve 80% power at the 0.05 significance level.

Results:

Left vs Right comparison

Of the 1128 perforated ears with middle ear diagnosis obtained from the original swimming pool study[18], 575 VO files (284 left; 291 right) with matching audiological data were obtained meeting the inclusion and exclusion criteria.

Chi-squared analysis revealed no difference between left and right ears in terms of activity (wet vs dry perforations) or size of perforations.

Activity of perforations and hearing loss

Active perforations (35dBHL; 28-44 IQR) had a significantly greater HL than inactive (31dBHL; 29-39 IQR) $p=0.0029$ (Fig 2).

Size of inactive perforations and hearing loss

Inactive perforations demonstrated a significant difference between <25% and all other larger perforations ($p<0.0001$), and between the 25-50% and 75-100% group ($p<0.05$) but there was no significant difference between other groups (Fig 3).

Size of active perforations and hearing loss

In contrast to the above finding, there was no significant difference between the <25% and 25-50% groups but significance was found between both the <25% ($p<0.0001$) and 25-50% ($p<0.05$) when compared the 50-75% group (Fig 4).

Location of perforations and hearing loss

When perforation location was compared within all size / activity groups, there were no statistically different findings identified (Table 1, Fig 5).

Comparison of pure-tone and 4-frequency pure tone average (4FPTA) hearing loss

When 4FPTA dBHL was compared to individual frequencies (0.5, 1, 2 & 4 kHz), identical results were obtained, both in terms of positive differences in perforation size and lack of significance for location within groups.

Discussion:

This study, to our knowledge, is the first describing the relationship between size, site and activity of perforations in ATSI children. In keeping with other studies[21], active mucosal COM created a greater HL than inactive disease. Multiple factors such as otorrhoea, mucosal hypertrophy, sclerotic change of the ossicles and generalised inflammation have been hypothesised to explain this finding[21].

Increasing TM perforation size also corresponded with an increase in HL. With active perforations, there was less hearing difference with increasing size compared to the inactive group, possibly due to oedema and fluid within the middle ear. We believe the absence of a significant increase in HL in both active and inactive perforations involving the 50-75% is due to the small number in the 50-75% group, making this a likely Type 1 error. An increase in HL with increased TM perforation size is consistent with the consensus of both theoretical and clinical studies in the literature[4, 6, 8, 10-12, 16]. In a study of 78 patients (107 ears) with inactive mucosal COM, perforations were classified as a percentage of total surface area using image processing software[8]. A strong correlation was found between HL and size of perforation[8]. A study of 300 ears divided perforations into small, medium and large using digital measurements[11]. The mean air-bone gap (ABG) increased with size[11]. This has been attributed to a decreased surface area for the amplification of sound, and a reduction in the area ratio between the TM and the stapes footplate[14]. The accuracy of perforation size estimated by 6 physicians was compared to objective software[7]. Between the doctors, agreement was high with kappa measures above 0.81 which compared favourably to the kappa of between 0.62 and 0.93 utilising the computer[7].

Our study found no difference in HL between frequencies across all perforation sizes and locations. This contradicts others that showed HL to be greater in the lower frequencies[4, 6, 8, 11, 21]. We hypothesise this may be due to the unique disease processes and lack of treatment in our patient group rather than the now discredited hypothesis of different anatomical factors between ATSI and Caucasian ears.

The literature regarding perforation location and hearing levels is conflicting. We found no statistically significant difference in hearing levels between perforation location and all size/activity groups. This is consistent with the findings of several studies using a variety of methods[6, 7, 12]. One study used audiometric data from 56 subjects (62 perforations) and found no statistically significant difference in the ABG between anterior and posterior perforations[6]. Another studied 38 patients (44 perforations), again with no statistically significant difference found between anterior and posterior perforations, both in terms of mean air conduction threshold, mean ABG, and frequency comparisons[12]. In 156 adult patients (172 perforations) undergoing myringoplasty for TM repair, there was no significant difference between pre-operative ABG between all quadrants for each frequency[7]. In 35 adult Nigerian patients (42 perforations), no significant difference was found between TM perforation location and HL in patients with pure conductive HL[22]. However, in patients with a mixed HL, the loss was greater for posterosuperior based perforations[22].

Several other studies also demonstrate increased HL with posterior perforations. Studies consistently utilise the manubrium mallei as the angled division between anterior and posterior[6-8, 10, 12, 15, 23]. However, the exact classification of location varies somewhat and is not often illustrated, making comparison difficult. Statistically significant findings from a number of studies found that posterosuperior[11, 15], posteroinferior[14] and posterior[8, 9, 13] perforations were associated with greater HL. In 70 young adult males (60 perforations) posteroinferior perforations had greater HL than anteroinferior perforations, with a greater difference apparent at low frequencies[14]. For perforations less than 10%, this difference was variable and inconsistent[14]. More recently, in the largest study thus far, 700 patients (1400 perforations) with inactive mucosal COM were studied[15]. Maximum HL was seen with posterosuperior perforations (48.6dB) and anterosuperior perforations had the least HL (24.0dB)[15]. When perforations involved 2 quadrants, involvement of a posterior quadrant resulted in higher HL compared to anterior quadrants but there was no significant difference between anteroinferior and posteroinferior quadrants[15]. One recent study found exclusively posterior perforations had a 12% greater ABG when compared with exclusively anterior perforations, however this was only significant at 500Hz[8]. Another looked at 90 ears and found the mean HL in anterior perforations was 29.9dB compared to the posterior perforation group with 44.9dB[13].

Many of these studies cite the "phase-cancellation effect" as a factor influencing HL for posterior perforations[8, 9, 13-15]. This hypothesises that a posterior perforation exposes the round and oval windows simultaneously to sound causing phase-cancellation and further increasing the level of HL[7, 21]. Contrary to this belief, experimental and theoretical studies by others[4, 6, 24, 25] found that perforation site did not affect pressure differences between the oval and round windows at all. Pressures were measured at the stapes and round windows in 11 temporal bones with no otologic disease[4]. When anteroinferior and posteroinferior perforations were then created, no pressure differences between the two sites were found whereas the main contributing factor to HL in TM perforations was the sound pressure difference across the TM[4]. The same group hypothesised that wavelengths of sound $<$4kHz are actually larger than the middle ear depth and therefore should not cause phase cancellation[6]. Additionally, one other compounding paper found that posteroinferior perforations had lower mean ABG levels than anteroinferior and posterosuperior locations by 12-14dB, thereby further contradicting the phase cancellation theory[11].

It is clear from the conflicting literature that there are likely to be other factors contributing to the variation in hearing levels with perforations at different locations. Involvement of the manubrium mallei has been discussed in many studies[12, 14, 21] with some finding perforations with malleolar involvement showed greater HL[15]. Additionally, in patients with disease lasting longer than 10 years, the average HL was greater at 52 dB compared to 36dB with disease durations of $<$1 year[15].

The volume of air in the middle ear and mastoid cell complex also appears to affect sound transmission. Using computed tomography[10] and tympanometry[6, 11, 12], mean ABGs correlated inversely with middle ear and mastoid volume[6, 10-12].

Perforation shape may also influence hearing levels with one study suggesting spindle-shaped perforations created greater conduction disturbance compared to circular perforations[21].

In a multivariate logistic regression analysis on 67 patients (86 perforations) aged 10 and over size of perforation proved to be the only significant predictor of HL severity[23].

The logistical challenges of data collection in our study population due to age, remoteness and resources mean that the variables measured in the literature cited above could unfortunately not be measured in this study.

This study has again demonstrated that children in the APY Lands are burdened with significant HL associated with potentially preventable and treatable disease. These findings assist with the qualitative estimation of HL from otoscopy based on size and site of the perforation. In resource poor areas such as the APY Lands, simple qualitative measures hold great value. Hearing losses greater than expected based on this data may indicate damage to other structures other than the TM.

Conclusion:

To the best of our knowledge this study is the first of its kind in school-aged children and in the ATSI population. We have demonstrated that perforation location does not significantly affect hearing levels in this population. Hearing loss was greater with activity and larger perforations. This study builds the foundation for further research into perforation characteristics and HL in this significantly affected population of children.

Funding information:

No funding was received for this study.

Conflict of interest

The authors declare no conflicts of interest.

Data availability statement

Data supporting the findings of this study are available from the corresponding author on request.

dBHL	<25%	25-50%	50-75%	75-100%
Total	28 (23-35)	34 (28-41)	40 (29-48)	39 (30-46)
AS	27 (22-35)			
AI	27 (23-35)			
PS	29 (26-36)			
PI	27 (23-33)			
Ant		31 (26-37)		
Inf		34 (27-44)		
Post		34 (26-39)		
AI			37 (26-46)	
PI			42 (32-51)	

Table 1: Hearing loss in inactive perforations by size and location. Reported as median 4FPTA dBHL (25-75 inter-quartile limits). AS: anterosuperior, AI: anteroinferior, PS: posterosuperior, PI: posteroinferior, Ant: anterior, Inf: inferior, Post: posterior.

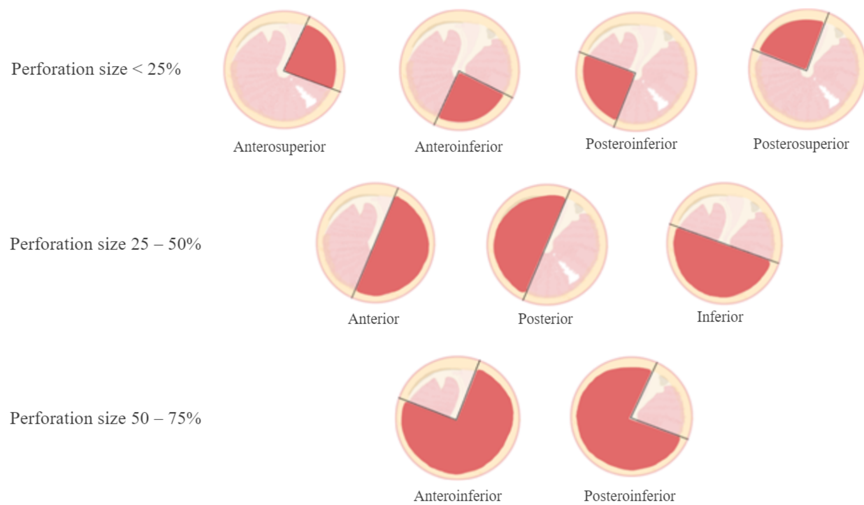


Figure 1: Classification of TM perforation site according to size and site. Perforations divided into areas based around the manubrium mallei.

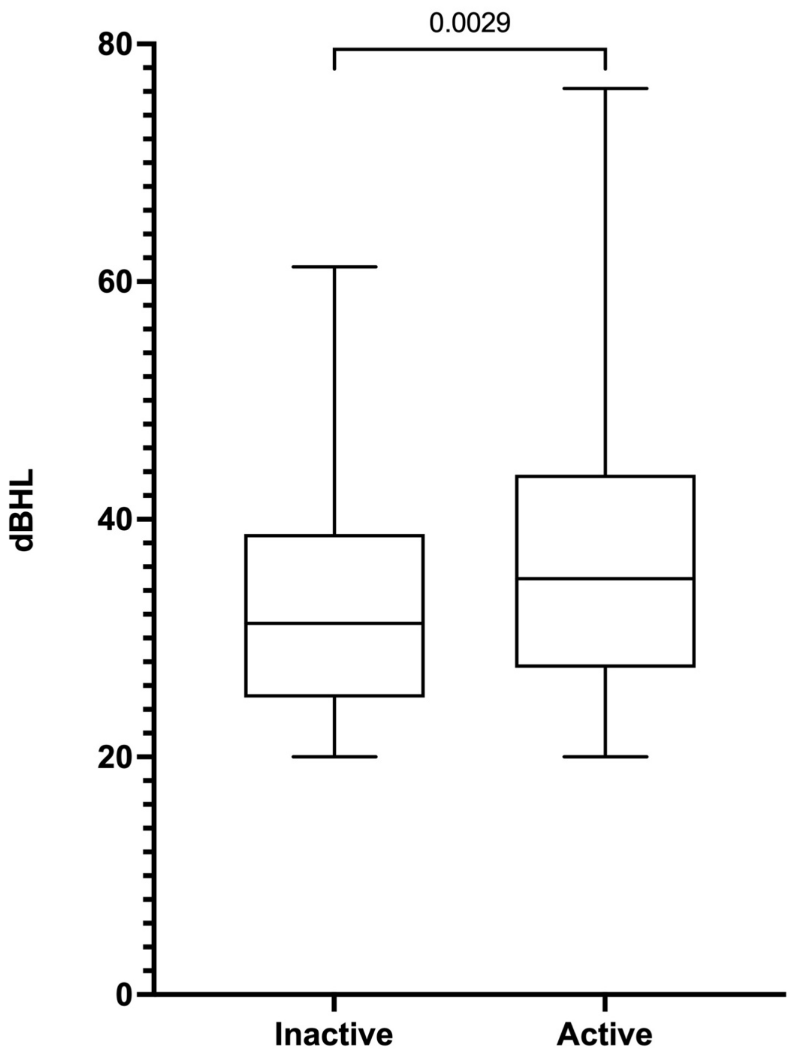


Figure 2: Hearing loss with active and inactive perforations (Median and quartile ranges).

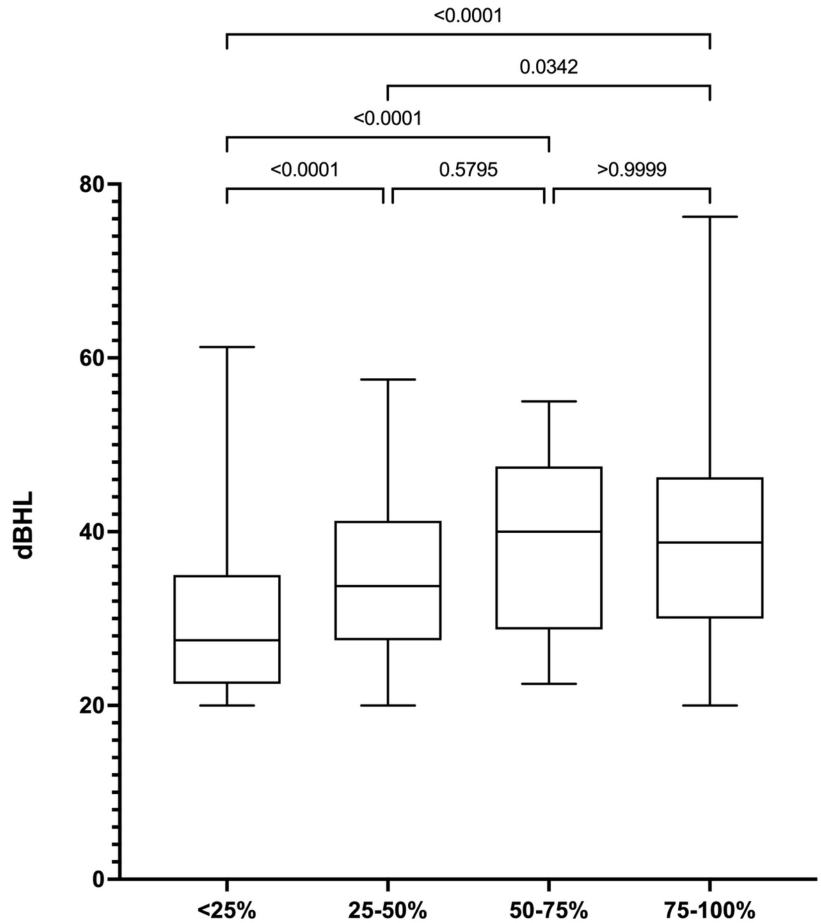


Figure 3: Hearing loss and size of inactive perforation (Median and quartile ranges).

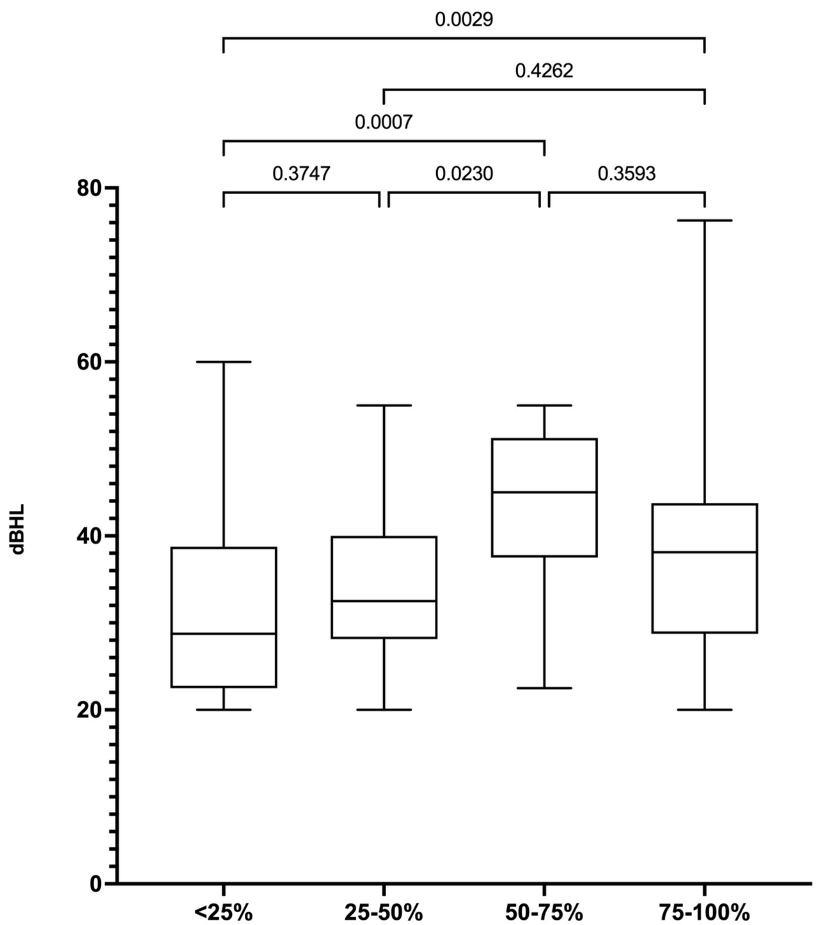
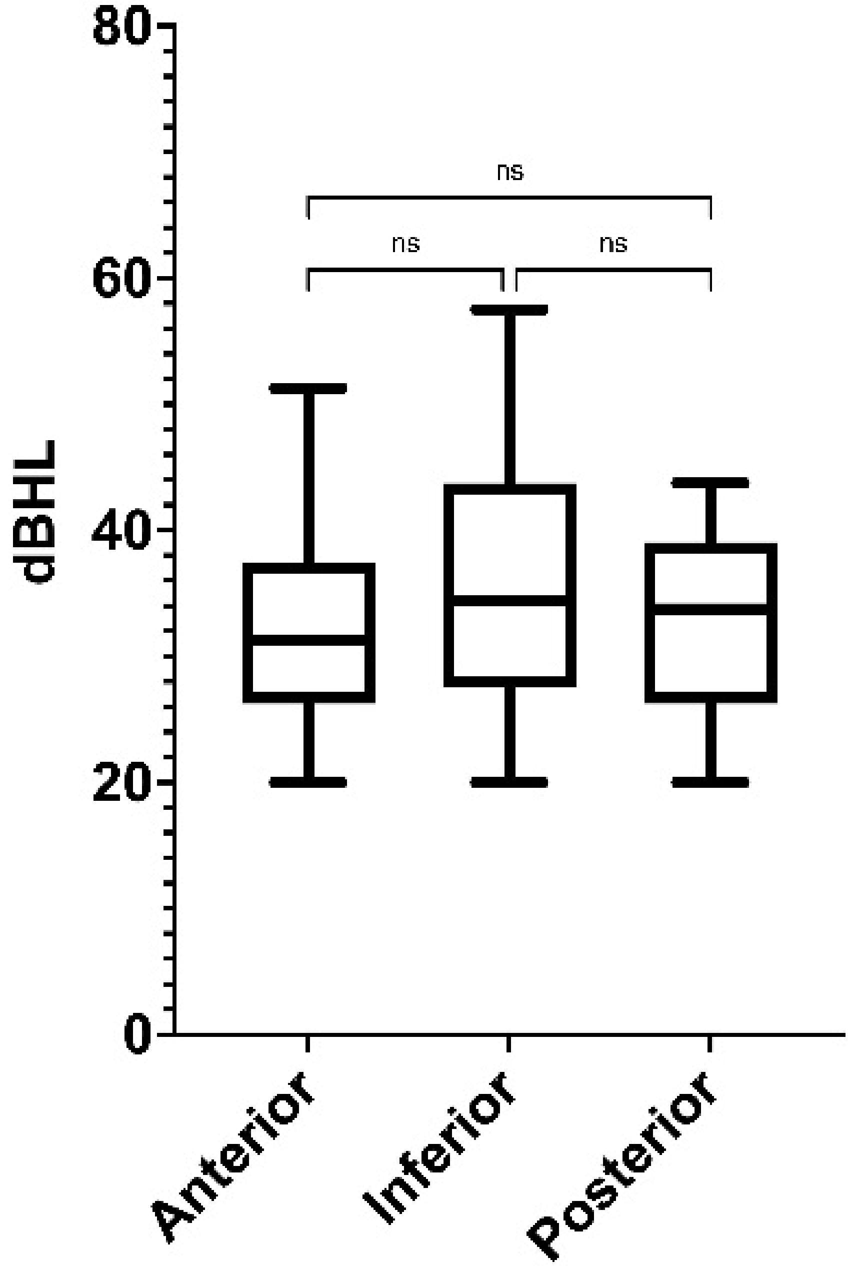


Figure 4: Hearing loss and size of active perforation (median and quartile ranges).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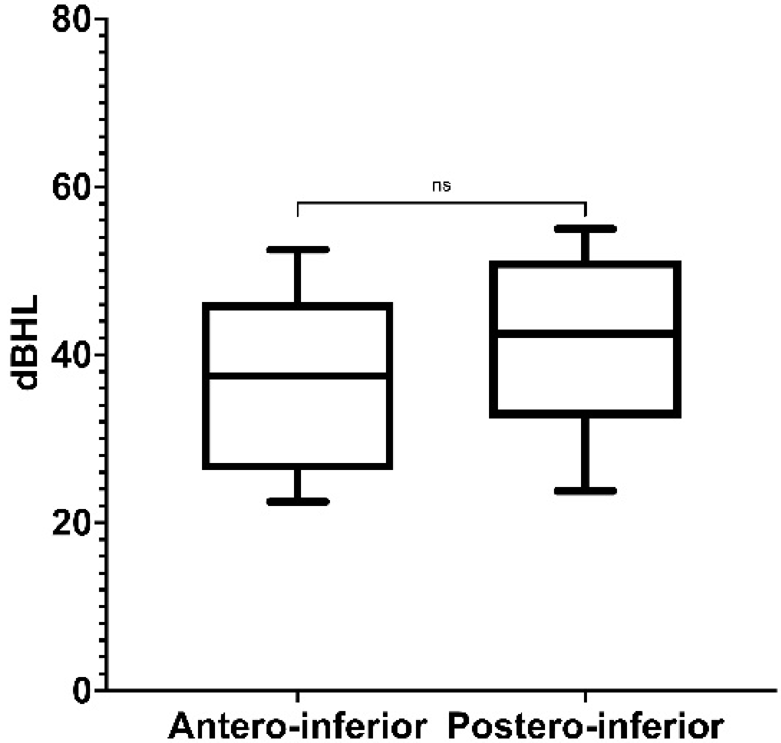
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Postero-inferior

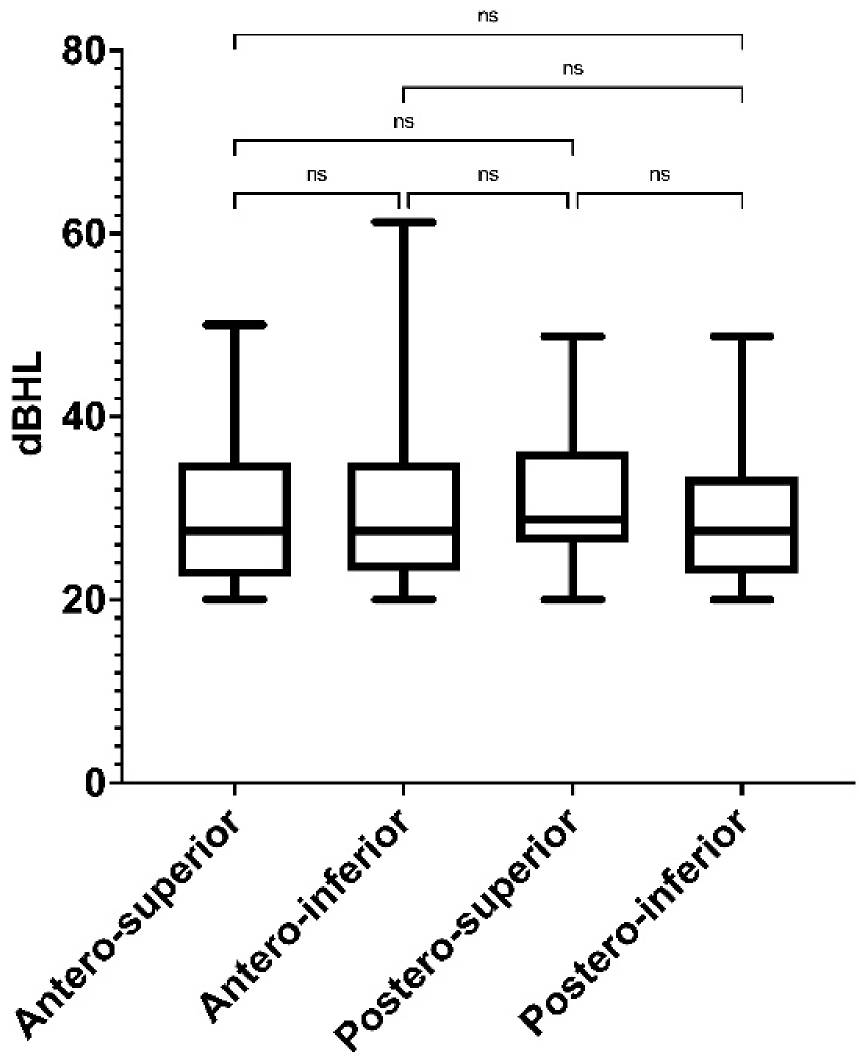

Figure 5: Comparison of hearing loss by location and size for inactive perforations (median and quartile ranges). Left to right: <25%, 25-50%, 50-75%.

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